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PATENT
EXPRESS MAIL NO. EL280219036US
Attorney Docket No. PD26112
Client/Matter No. 34309.830054.000

THE ASSISTANT COMMISSIONER FOR PATENTS
Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application of

Inventors: Bruning, et al.

For: APPARATUS AND METHOD FOR PROVIDING VERY LARGE VIRTUAL STORAGE VOLUMES USING REDUNDANT ARRAYS OF DISKS

Enclosed are:

☒ 3 sheets of drawing.

☒ An assignment of the invention to Digital Equipment Corporation.

☐ A certified copy of a _____ application

☒ A signed Power of Attorney by Assignee.

☐ A verified statement to establish small entity status under 37 CFR 1.9 and 37 CFR 1.27.

☒ A signed Declaration.

☒ Check in the amount of $994.

The filing fee has been calculated as shown below:

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BASIC FEE				$380	OR		$ 760
TOTAL CLAIMS	20-20 =	-0-	x 9 =	$	OR	x18 =	$ -0-
INDEP CLAIMS	6 -3 =	3	x39 =	$	OR	x78 =	$ 234
☐ MULTIPLE DEPENDENT CLAIM PRESENTED			x130 =	$-0-	OR	+260 =	$ -0-
			TOTAL	$	OR	TOTAL	$ 994

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☒ Any patent application processing fees under 37 CFR 17.

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☒ Any filing fees under 37 CFR 1.16 for presentation of extra claims.

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5 April 1999

PATENT
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Client/Matter No. 34309.830054.000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

Bruning, et al.

Serial No. _____

Filed: Herewith

For: APPARATUS AND METHOD FOR PROVIDING VERY LARGE VIRTUAL STORAGE VOLUMES USING REDUNDANT ARRAYS OF DISKS

Group Art Unit: _____

Examiner: _____

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Sir:

The undersigned hereby certifies that the following documents:

1. Transmittal letter for Patent Application;
2. Utility Patent Application;
3. Executed Declaration;
4. Executed Power of Attorney by Assignee
5. 3 sheets of drawings;
6. Recordation Form Cover Sheet PTO 1595 with Executed Assignment and Recording Fee of $40.00;
7. $ 994 filing fee;
8. Return postcard; and
9. Certificate of Mailing By Express Mail

relating to the above application, were deposited as "Express Mail", Mailing Label No. EL280219036US with the United States Postal Service, addressed to The Commissioner of Patents and Trademarks, Washington, D.C., 20231, April 5, 1999.

April 5, 1999
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Date

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PATENT APPLICATION

for an

APPARATUS AND METHOD FOR PROVIDING VERY LARGE VIRTUAL STORAGE VOLUMES USING REDUNDANT ARRAYS OF DISKS

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APPARATUS AND METHOD FOR PROVIDING VERY LARGE VIRTUAL STORAGE VOLUMES USING REDUNDANT ARRAYS OF DISKS

TECHNICAL FIELD OF THE INVENTION

This invention relates in general to redundant arrays of disks, such as RAID (Redundant Array of Independent Disks) sets. More specifically, the invention relates to an apparatus and method for providing virtual storage volumes, particularly very large virtual storage volumes (*e.g.*, 100 Gigabytes (GB) or more), using redundant arrays of disks, such as RAID sets.

BACKGROUND OF THE INVENTION

Some computer software applications are organized according to what is referred to as a "single volume architecture," meaning that they store data in a single data file that resides on a single volume. This "volume" may be a physical volume, such as a disk drive, or it may be a virtual volume, such as a RAID set. The Exchange® e-mail program provided by Microsoft Corporation of Redmond, Washington is an example of such a single-volume-architecture application.

In some cases, the single volume architecture of a particular software application can be problematic, because the size of the data file the application needs to store on a single volume exceeds the capacity of the volume. For example, implementations of Microsoft's Exchange® e-mail program in large organizations having many e-mail users can require a single-volume storage capacity exceeding 100GB, which is greater than many conventional volumes, physical or virtual, can provide. Although it is possible to solve this problem by changing a single-volume-architecture application into a multi-volume-architecture application so that it saves data in multiple files spread across multiple volumes, such efforts can be prohibitively time-consuming and expensive.

Accordingly, there is a need in the art for a very large virtual storage volume having the storage capacity necessary to meet the needs of a single-volume-architecture software application, such as Microsoft's Exchange® e-mail program. Preferably, such a storage volume should have built-in disaster tolerance capabilities through the use of remote mirroring or other techniques in order to ensure the integrity of its stored data. In addition, such a storage volume should preferably have cloning

capabilities so that data backup can occur off-line without interrupting read/write access to the data.

SUMMARY OF THE INVENTION

An inventive apparatus for providing a very large storage volume includes a plurality of disks and a local back-end controller that organizes and presents the disks as redundant arrays of disks (*e.g.*, RAID-5 sets). Also, a local front-end controller stripes the redundant arrays of disks and presents the striped arrays as a very large storage volume.

To provide local redundancy, another plurality of disks and an associated back-end controller can be provided, in which case the local front-end controller forms mirror sets from the redundant arrays of disks presented by both back-end controllers. In addition, a further plurality of disks and an associated back-end controller can be provided to enable off-line backup of the data stored on the volume by cloning the data onto the disks, and then using the disks as the data source for off-line backup. Also, a still further plurality of disks and an associated back-end controller can be provided at a remote location to protect against disasters occurring at the primary location (commonly referred to as "disaster tolerance"). The disks and back-end controllers providing cloning capabilities and disaster tolerance can be incorporated into the mirror sets formed by the local front-end controller. Further, spare disks can be provided on any or all of the back-end controllers to allow restoration of redundancy after the loss of any particular disk.

If, for example, the disks each have 9.1GB of storage capacity and the local back-end controller organizes the disks into eleven, six-member RAID-5 sets, then the very large storage volume has a storage capacity in excess of 500GB, which should be adequate for most single-volume architecture programs. In addition, the redundancy restoration capabilities provided by the spare disks, the parity associated with RAID-5 sets, and the mirroring ensures the integrity of the data stored on the very large storage volume.

In another embodiment of this invention, the apparatus described above can be incorporated into an electronic system that also includes a host computer.

In a further embodiment of this invention, data is stored on a plurality of disks by organizing the disks into a plurality of redundant arrays of disks. The redundant

arrays of disks are striped together to form a virtual volume, and the data is then written to the virtual volume.

In still another embodiment of this invention, data is again stored on a plurality of disks by organizing the disks into a plurality of redundant arrays of disks. Mirror sets are formed from the redundant arrays of disks, and these mirror sets are then striped together to form a virtual volume. The data is then written to the virtual volume.

BRIEF DESCRIPTION OF THE FIGURES

Figures 1A and 1B is a diagram illustrating the organization of a very large volume constructed in accordance with this invention; and

Figure 2 is a block diagram illustrating the very large volume of Figures 1A and 1B.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

As shown in Figures 1A and 1B, a 500.5GB very large volume **10** constructed in accordance with this invention is organized so as to comprise a RAID-0 stripe set having eleven, 45.5GB RAID-1 mirror sets **M1-M11** as members. Of course, it will be understood by those having skill in the technical field of this invention that although the invention will be described with respect to a very large volume having a 500.5GB storage capacity, the invention is not limited to any particular storage capacity. In addition, it will be understood that the invention is not limited to the use of any particular redundant array technology (*e.g.*, RAID) and, consequently, is not limited to the use of any particular RAID levels (*e.g.*, RAID-0, RAID-1). Also, it will be understood that the invention may include more or less than the eleven mirror sets **M1-M11**, and that the individual mirror sets **M1-M11** may be larger or smaller in size than the 45.5GB described here.

As used herein, a "RAID-0 stripe set" will be understood to refer to a virtual volume comprised of two or more member disks or volumes across which "stripes" of data are stored. Also, as used herein, a "RAID-1 mirror set" will be understood to refer to a virtual volume comprised of two or more member disks or volumes, each of which contains an identical copy of the data stored in the mirror set.

The mirror set **M1**, for example, comprises five, 45.5GB RAID-5 sets **PL1**, **RL1**, **C1**, **PR1**, and **RR1** as members. Similarly, the mirror set **M11** comprises five, 45.5GB RAID-5 sets **PL11**, **RL11**, **C11**, **PR11**, and **RR11** as members. For purposes of clarity, the RAID-5 set members of the mirror sets **M2-M10** are illustrated but not labeled.

Of course, it will be understood that the members of the mirror sets **M1-M11** can be other than RAID-5 sets (*e.g.*, RAID-3 or RAID-4 sets). Also, as used herein, a "RAID-5 set" will be understood to refer to a virtual volume comprised of three or more independently accessible member disks or volumes having redundancy protection through parity information distributed across its members.

The RAID-5 sets **PL1-PL11** comprise the primary local storage copy of the data stored in the very large volume **10**, which means that they are the primary location to which the data is written and from which the data is read. Also, the RAID-5 sets **RL1-RL11** comprise a redundant local storage copy of the data, which provides mirroring-type redundancy for the stored data. In addition, the RAID-5 sets **C1-C11** comprise a cloning storage copy of the data, which is convenient for use in performing off-line data backups without interrupting read/write activities to the very large volume **10**. Disaster tolerance is provided by the RAID-5 sets **PR1-PR11**, which comprise a primary remote storage copy, and the RAID-5 sets **RR1-RR11**, which comprise a redundant remote storage copy. Of course, it should be understood that embodiments of this invention may exclude the redundancy provided by the RAID-5 sets **RL1-RL11**, the cloning capability provided by the RAID-5 sets **C1-C11**, or the disaster tolerance provided by the RAID-5 sets **PR1-PR11** and **RR1-RR11**.

The RAID-5 set **PL1**, for example, comprises six, 9.1GB physical disks **12** distributed across six SCSI busses **bus1-bus6** of a back-end controller (*see* Figure 2). Similarly, the RAID-5 set **PL11** comprises six, 9.1GB physical disks **14** distributed across the six SCSI busses **bus1-bus6**. In addition, six, 9.1GB spare physical disks **16** seamlessly replace any failing disks on any of the busses **bus1-bus6** by rebuilding the data stored on failing disks from parity data, thereby restoring redundancy after a disk failure.

As described herein, the very large volume **10** has a high degree of redundancy. If the **bus3** physical disk **12** fails, for example, it is replaced by the **bus3** spare disk **16** by using parity data to rebuild the data stored on the failing **bus3**

physical disk **12** onto the replacement **bus3** spare disk **16**. If **bus3** itself fails, for example, the parity redundancy in the RAID-5 sets **PL1-PL11** regenerates the data stored on the failing **bus3**. If the back-end controller (*see* Figure 2) associated with the RAID-5 sets **PL1-PL11** fails, for example, the redundant local storage copy, comprised of the RAID-5 sets **RL1-RL11**, provides redundancy. Finally, if the front-end controller (*see* Figure 2) associated with the primary and redundant local storage copies and the cloning storage copy fails or is destroyed (*e.g.*, due to a disaster), the primary remote storage copy, comprised of the RAID-5 sets **PR1-PR11**, and the redundant remote storage copy, comprised of the RAID-5 sets **RR1-RR11**, provide redundancy.

As shown in a block diagram in Figure 2, the very large volume **10** is connected to a local host computer **20** that reads data from, and writes data to, the volume **10** via a local front-end controller **22** that acts as a mirroring and striping engine. In other words, the controller **22** forms the mirror sets **M1-M11** (*see* Figures 1A and 1B) and then stripes them so as to present them to the local host computer **20** as the very large volume **10**.

The primary local storage copy comprises physical disks **24** (which include disks **12**, **14**, and **16** of Figures 1A and 1B) connected to a back-end controller **26**. The controller **26** acts as a RAID-5 engine by forming the disks **24** into the RAID-5 sets **PL1-PL11** (*see* Figures 1A and 1B) and presenting the sets **PL1-PL11** to the front-end controller **22** as members. Similarly, the redundant local storage, clone, primary remote storage, and redundant remote storage copies comprise physical disks **28**, **30**, **32**, and **34**, respectively, connected to back-end controllers **36**, **38**, **40**, and **42**, respectively, that act as RAID-5 engines by forming the disks **28**, **30**, **32**, and **34** into the RAID-5 sets **RL1-RL11**, **C1-C11**, **PR1-PR11**, and **RR1-RR11** and presenting these sets to front-end controller **22** as members.

In addition, the very large volume **10** is connected to a remote host computer **44** that reads data from, and writes data to, the volume **10** via a remote front-end controller **46** that acts as a mirroring and striping engine for the primary and redundant remote storage copies. The local and remote host computers **20** and **44** are connected via a network interconnect **48**, such as the internet or a dedicated network line.

In an alternative embodiment, the front-end controller **22** can be configured to present a 273GB unit and a 227.5GB unit to the local host computer **20**, rather than the single 500.5GB unit described above. Of course, it should be understood that the front-end controller **22** can, in fact, be configured in a multitude of ways to group the mirror sets **M1-11** into between one and eleven total units, each potentially ranging in size from 45.5GB to 500.5GB. Further, it should be understood that the front-end controller **22** can be configured (typically using software) to partition the striped mirror sets **M1-11** into an infinite number and size of units.

In addition, it should be understood that although this invention has been described with reference to an embodiment having two levels of stacked controllers, the invention is not limited to the two levels described. Rather, the invention includes within its scope any number of levels of stacked controllers.

Although this invention has been described with reference to particular embodiments, the invention is not limited to these described embodiments. Rather, the invention is limited only by the appended claims, which include within their scope all equivalent devices and methods that operate according to the principles of the invention as described.

CLAIMS

1. An apparatus for providing a virtual volume, the apparatus comprising:

a plurality of disks;

a back-end controller coupled to the disks for organizing and presenting the disks as a plurality of redundant arrays of disks; and

a front-end controller coupled to the back-end controller for striping the redundant arrays of disks and presenting the striped arrays as a virtual volume.

2. The apparatus of claim 1 wherein the plurality of disks includes one or more spare disks.

3. The apparatus of claim 1 wherein the back-end controller includes a plurality of busses, each coupled to one and only one of the disks associated with each of the redundant arrays of disks.

4. The apparatus of claim 1 wherein the back-end controller comprises a RAID engine for presenting the disks as a plurality of RAID sets.

5. The apparatus of claim 4 wherein the RAID engine comprises a RAID engine for presenting the disks as a plurality of RAID-5 sets.

6. An apparatus for providing a virtual volume, the apparatus comprising:

a plurality of disks;

a RAID engine coupled to the disks for organizing and presenting the disks as a plurality of RAID sets; and

a striping engine coupled to the RAID engine for receiving the RAID sets as members, striping the member RAID sets, and presenting the striped RAID sets as a virtual volume.

7. The apparatus of claim 6 wherein the RAID engine comprises a RAID-5 engine.

8. An apparatus for providing a virtual volume, the apparatus comprising:

a plurality of back-end controllers, each configured to organize and present X N-member RAID sets, and each having N busses capable of supporting X+1 disks each;

a plurality of groups of X+1 disks, each group being coupled to one of the back-end controller busses; and

a local front-end controller coupled to the back-end controllers for receiving the RAID sets as members, striping the member RAID sets, and presenting the striped RAID sets as a virtual volume.

9. The apparatus of claim 8 wherein the local front-end controller is configured to generate mirror sets from the RAID sets received as members from different back-end controllers, to stripe the mirror sets, and to present the striped mirror sets as the virtual volume.

10. The apparatus of claim 8 wherein the plurality of back-end controllers includes primary local, redundant local, cloning, primary remote, and redundant remote back-end controllers.

11. The apparatus of claim 8 further comprising a remote front-end controller coupled to at least some of the back-end controllers for receiving RAID sets as members, striping the member RAID sets, and presenting the striped RAID sets as the virtual volume.

12. The apparatus of claim 11 wherein the remote front-end controller is configured to generate mirror sets from the received RAID sets, to stripe the mirror sets, and to present the striped mirror sets as the virtual volume.

13. An electronic system comprising:

a computer; and

an apparatus coupled to the computer for presenting a virtual volume to the computer, the apparatus including:

a plurality of disks;

a back-end controller coupled to the disks for organizing and presenting the disks as a plurality of redundant arrays of disks; and

a front-end controller coupled to the back-end controller for striping the redundant arrays of disks and presenting the striped arrays as the virtual volume.

14. A method of storing data on a plurality of disks, the method comprising:

organizing the disks into a plurality of redundant arrays of disks;

striping the redundant arrays of disks together to form a virtual volume; and

writing the data to the virtual volume.

15. The method of claim 14 wherein the act of organizing the disks comprises organizing the disks into a plurality of RAID sets.

16. The method of claim 15 wherein the act of organizing the disks comprises organizing the disks into a plurality of RAID-5 sets.

17. The method of claim 14 wherein the act of organizing the disks includes:

providing one or more back-end controllers, each having a plurality of busses; and

coupling the disks to the back-end controller busses so that each bus is coupled to no more than one disk from each redundant array of disks and each bus is coupled to a spare disk.

18. A method of storing data on a plurality of disks, the method comprising:

organizing the disks into a plurality of redundant arrays of disks;

forming mirror sets from the redundant arrays of disks;

striping the mirror sets together to form a virtual volume; and

writing the data to the virtual volume.

19. The method of claim 18 wherein the act of organizing the disks comprises organizing the disks into a plurality of RAID sets.

20. The method of claim 19 wherein the act of organizing the disks comprises organizing the disks into a plurality of RAID-5 sets.

ABSTRACT OF THE DISCLOSURE

A very large virtual volume (*e.g.*, in excess of 500GB) is formed by distributing the disks in eleven, six-disk RAID-5 sets across the six busses of a primary local back-end controller. A spare disk is provided on each of the six busses. Each RAID-5 set is protected from the failure of a single disk by the spare disks on the busses, which can use the parity data stored in a RAID-5 set to rebuild the data stored on a failing disk and thereby restore redundancy to the RAID-5 set. Each RAID-5 set is also protected from the failure of a bus by the parity inherent in RAID-5. The RAID-5 sets are striped by a front-end controller connected to the primary local back-end controller, and the striped RAID-5 sets are presented to a host computer as a very large virtual volume. If the individual disks are 9.1GB in size, the size of the very large virtual volume can reach 500.5GB. If desired, additional groups of eleven, six-disk RAID-5 sets can be formed on additional back-end controllers for purposes of redundancy, cloning (which generates a copy of the data that can be used for off-line backup without interrupting read/write activities on the virtual volume), and disaster tolerance through remote storage. These additional groups of RAID-5 sets, along with the RAID-5 sets from the primary local back-end controller, can be formed into mirror sets by the front-end controller, which then stripes the mirror sets and presents the striped mirror sets to the host computer as the very large virtual volume.

FIG. 1A	FIG. 1B

FIG. 1

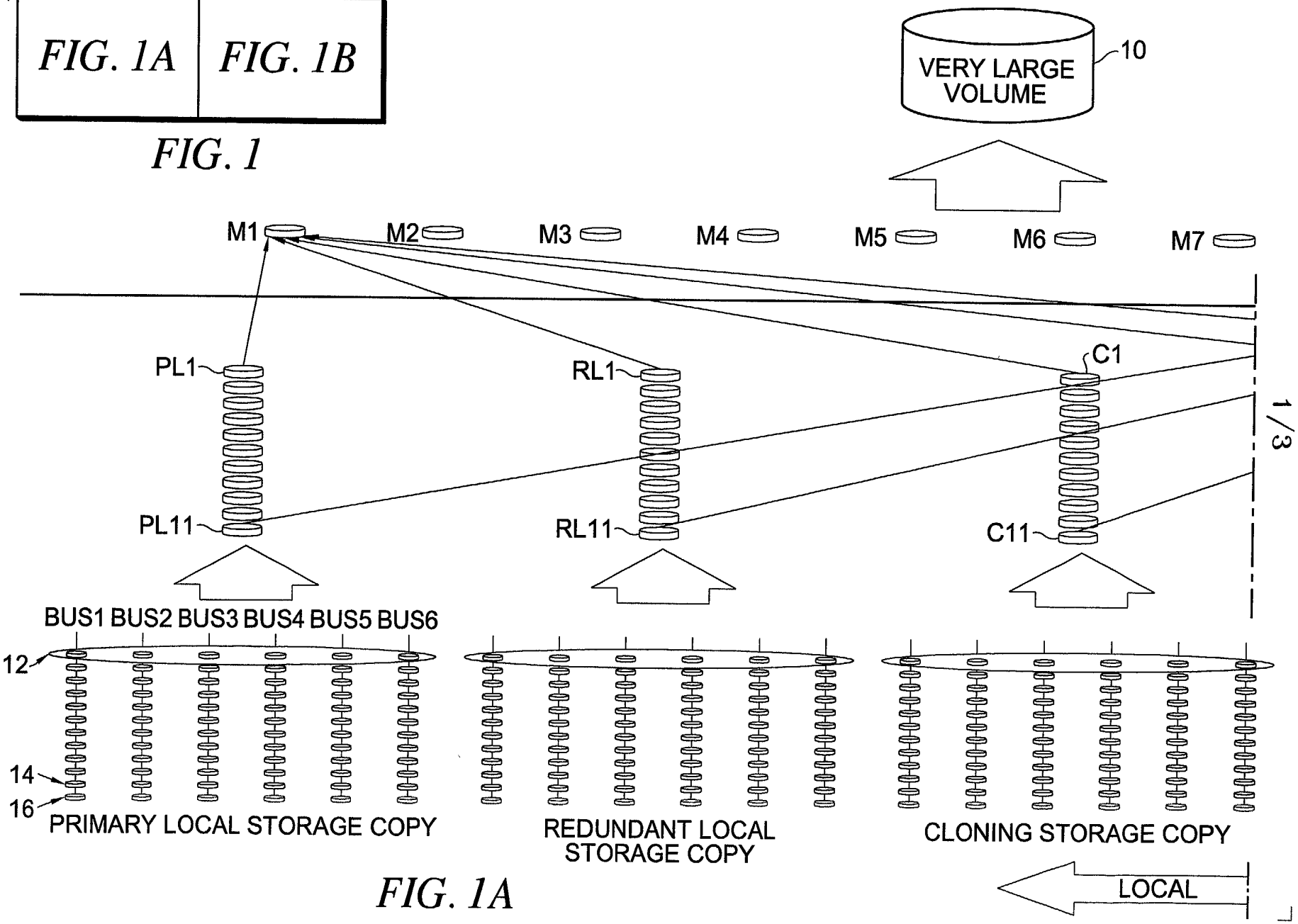

FIG. 1A

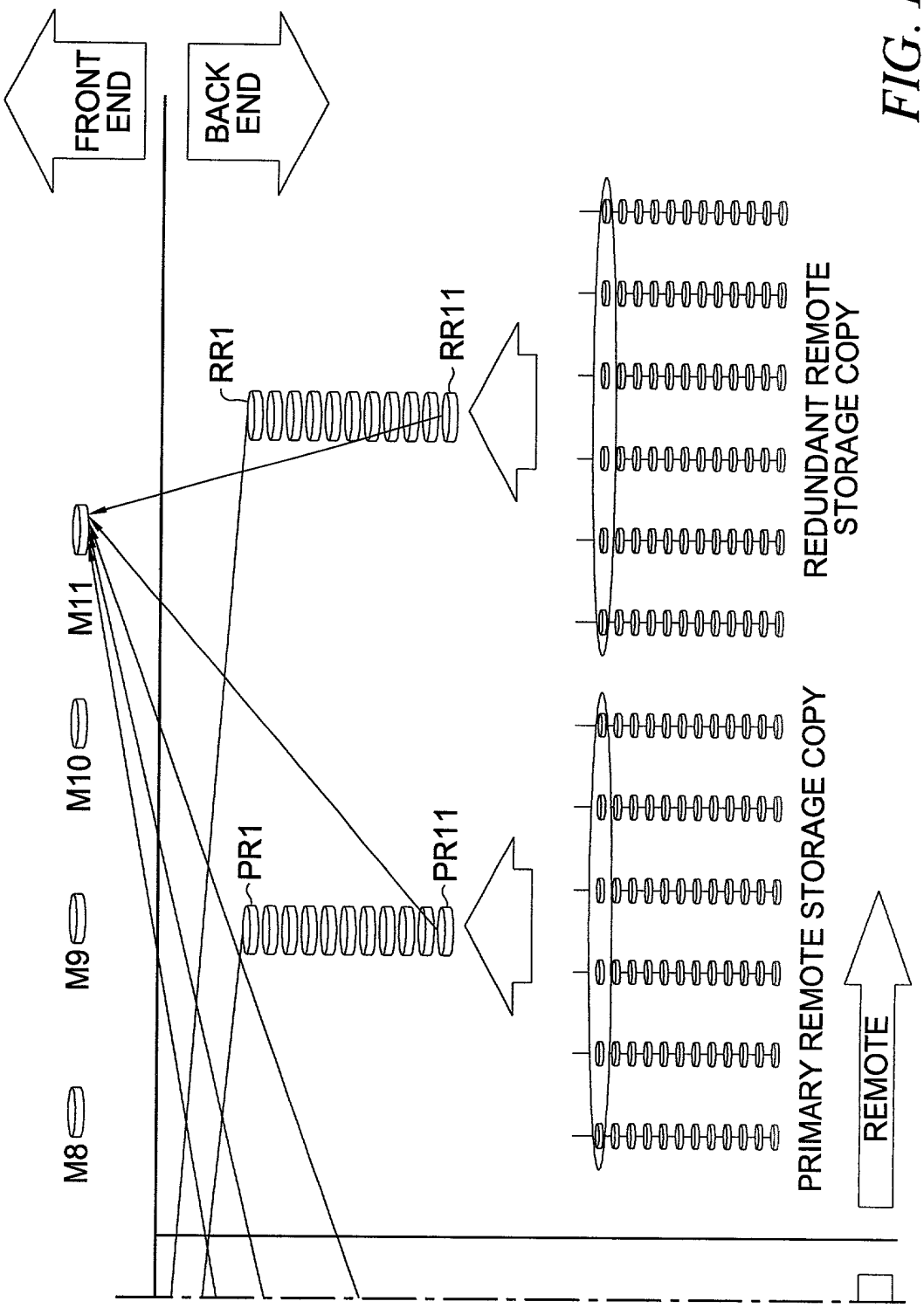
FRONT END
BACK END
M8
M9
M10
M11
PR1
PR11
RR1
RR11
PRIMARY REMOTE STORAGE COPY
REDUNDANT REMOTE STORAGE COPY
REMOTE

FIG. 1B

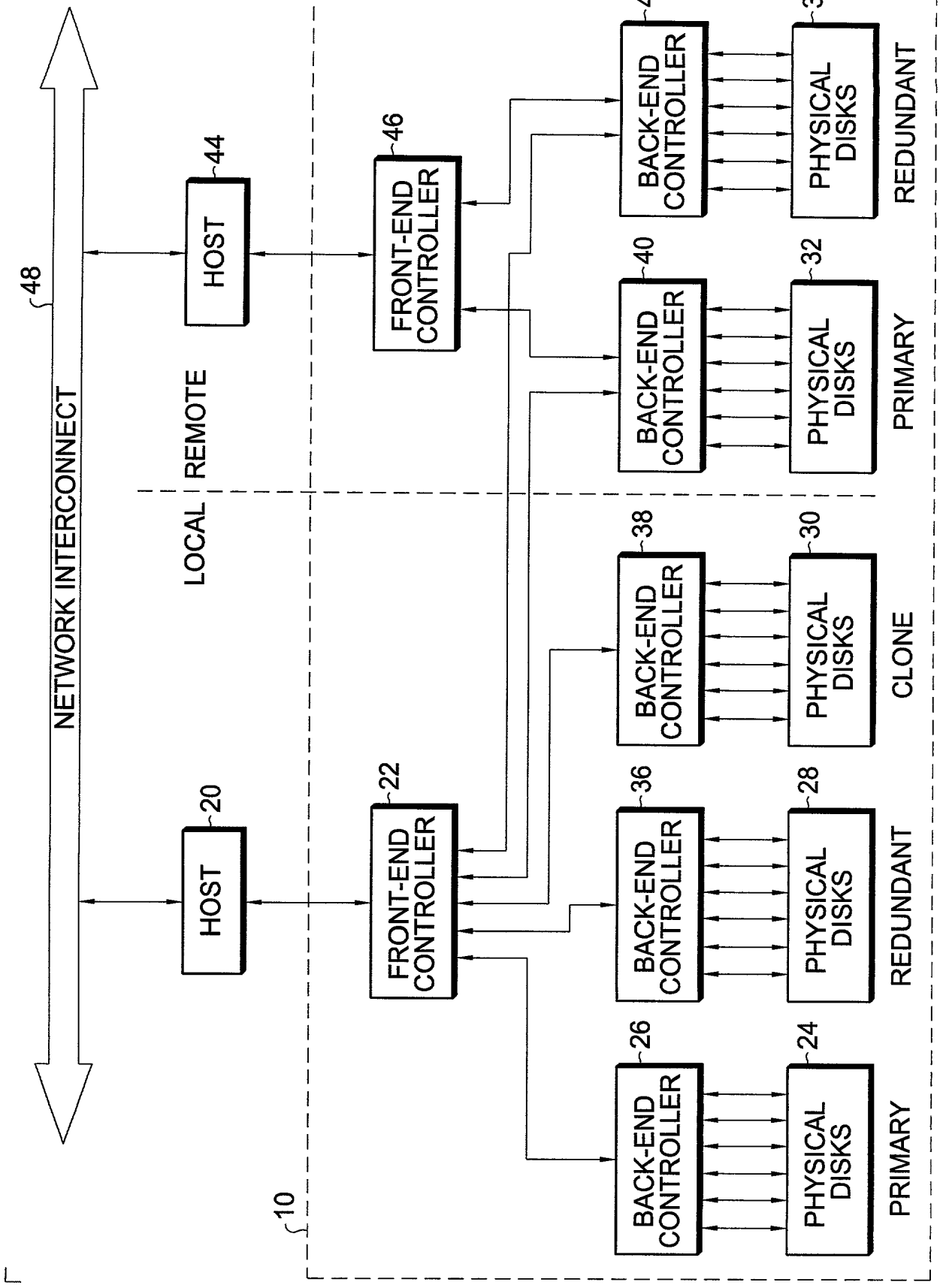
NETWORK INTERCONNECT
48
HOST
20
HOST
44
FRONT-END CONTROLLER
22
FRONT-END CONTROLLER
46
LOCAL
REMOTE
BACK-END CONTROLLER
26
BACK-END CONTROLLER
36
BACK-END CONTROLLER
38
BACK-END CONTROLLER
40
BACK-END CONTROLLER
42
PHYSICAL DISKS
24
PHYSICAL DISKS
28
PHYSICAL DISKS
30
PHYSICAL DISKS
32
PHYSICAL DISKS
34
PRIMARY
REDUNDANT
CLONE
PRIMARY
REDUNDANT
10

FIG. 2

PATENT
Attorney Docket No. PD26112
Client/Matter No. 34309.830054.000
Express Mail No. EL280219036US
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Original

DECLARATION

As a below named inventor, I hereby declare that: my residence, post office address, and citizenship are as stated below next to my name. I believe I am the original, first, and sole inventor (if only one name is listed below) or a joint inventor (if plural inventors are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

APPARATUS AND METHOD FOR PROVIDING VERY LARGE VIRTUAL STORAGE VOLUMES USING REDUNDANT ARRAYS OF DISKS

as described in the specification ☒ attached or ☐ of patent Application Serial No. _____ filed herewith and amended on _____.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above; that I do not know and do not believe the same was ever known or used in the United States of America before my or our invention thereof, or patented or described in any printed publication in any country before my or our invention thereof or more than one year prior to this application; that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representative or assigns more than twelve months prior to this application; and that I acknowledge the duty to disclose information of which I am aware which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations § 1.56(a). Such information is material when it is not cumulative to information already of record or being made of record in the application, and

(1) it establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or
(2) it refutes, or is inconsistent with, a position the applicant has taken or may take in:
(i) opposing an argument of unpatentability relied on by the Office, or
(ii) asserting an argument of unpatentability.

I hereby claim foreign priority benefits under Title 35, United States Code § 119 of any foreign application(s) for patent or inventor's certificates listed below and have also identified below any foreign application(s) having a filing date before that of the applications(s) on which priority is claimed:

COUNTRY	APPLICATION NUMBER	Date Filed	Priority Claimed under 35 USC 119
			☐ YES ☐ NO

I hereby claim the benefit under Title 35 United States Code § 120 of any United States application(s) listed below and, insofar as any subject matter of any claim of this application is not disclosed in the prior United States Application, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations § 1.56(a) which occurred between the filing date of the prior application and the national PCT international filing date of this application.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant/Patentee: Bruning, et al.

Serial No.: _____

Date Filed: Herewith

For: APPARATUS AND METHOD FOR PROVIDING VERY LARGE VIRTUAL STORAGE VOLUMES USING REDUNDANT ARRAYS OF DISKS

Attorney File No.: 34309.830054.000

Digital Docket No.: PD26112

POWER OF ATTORNEY BY ASSIGNEE

Under the provisions of 37 C.F.R. § 3.71, the undersigned assignee of record of the entire interest in the above-identified patent/patent application by virtue of an assignment recorded (check as applicable):

☒ Concurrently Herewith
☐ Date Recorded _____
☐ Reel _____ Frame _____

elects to conduct the prosecution of the application/maintenance of the patent to the exclusion of the inventor(s). The undersigned hereby declares that she has reviewed the above-referenced assignment and hereby declares that, to the best of her knowledge, title is in the Assignee, and further declares that all statements made herein of her own knowledge are true and that all statements made on information and belief are believed to be true. The assignee hereby revokes any previous powers of attorney and appoints the following to prosecute this application/maintain this patent and transact all business in the Patent and Trademark Office connected therewith:

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Authorized To Sign This Document On Behalf Of Digital Equipment Corporation
Pursuant To Board of Directors Resolution Dated: September 25, 1998